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Procedia Social and Behavioral Sciences 41 (2010) 6661–6669

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**Procedia**  
Social and Behavioral Sciences

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Selected Papers of Beijing Forum 2008

# Air Pollution and Human Health: From Local to Global Issues

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## Abstract

Air pollution from fossil fuel combustion has been known to affect human health for centuries. More detailed insights developed in the 20th century, as a result of studies prompted by severe air pollution episodes such as those in the Meuse Valley, Belgium in 1930, and London, UK in 1952. The focus in the early studies was on local pollution produced by industry, power generation and home heating sources. Later, the emphasis shifted to so-called secondary pollutants, the products of atmospheric reactions producing pollutants such as ozone, sulphates and nitrates. The secondary pollutants typically affected large areas extending hundreds of kilometers downwind from primary sources. Effects of secondary pollutants on human health became evident from population studies and, in case of ozone, also from controlled human laboratory experiments.

On an even larger scale, we are now confronted with air pollution masses extending over thousands of kilometers, and occupying several kilometers of the troposphere, the so-called ‘brown clouds’. Emissions from megacities, industry, energy production plants, home heating, biomass combustion for cooking and heating in rural areas as well as wildfires contribute to these ‘brown clouds’. Adverse effects of such clouds on human health are suspected but have not yet been conclusively proven.

On the other end of the spatial scale, it has become convincingly clear that at the very local level, indoor air pollution from biomass combustion and exposure to traffic-related air pollution constitute major health hazards.

Developing economies such as in China are confronted with each of these types of air pollution simultaneously, posing tremendous challenges for public health policy.

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## Introduction

Air pollution from fossil fuel combustion has been known to affect human health for centuries. More detailed insights developed in the 20<sup>th</sup> century, as a result of studies prompted by severe air pollution episodes such as those in the Meuse Valley, Belgium in 1930, and London, UK in 1952. In the Meuse Valley, stagnant weather conditions prevented local, industry-generated pollutants from dispersing during several days in December 1930 (1). Several dozens of people died suddenly, and the episode attracted worldwide attention. In December 1952, stagnant weather conditions prevented local pollution dominated by coal smoke from dispersing in London, UK. It was initially estimated that some 4,000 people died as a result, but later estimates, taking into account delayed effects in the following months, put the figure at perhaps as high as 10,000 (2). In the second part of the 20<sup>th</sup> century, pollution abatement measures were taken in many developed countries as a result of these dramatic events, and urban pollution levels declined. Emphasis shifted to secondary pollutants formed in the atmosphere as a result of chemical

reactions, notably ozone and fine particles. Many studies have been published on the health effects of these pollutants, showing that day-to-day variations in their levels are associated with adverse health outcomes including mortality even at very low levels of exposure. For ozone, the associations with mortality are a relatively recent finding that was confirmed by three independent reviews (3–5). Associations between particulate matter and health have been reported from many areas (6). This review discussed six dimensions of associations between ambient PM and health: 1) short term exposure and mortality; 2) long term exposure and mortality; 3) time scales of exposure; 4) the shape of the concentration-response function; 5) cardiovascular disease; and 6) biological plausibility.

1) Short term exposure and mortality: a very large number of time series studies have by now addressed this topic. Several of these were multi-center studies, using data from many different cities that were analyzed using a common analysis protocol. Examples of these are the National Mortality and Morbidity Air Pollution Studies (NMMAPS) in the United States and the “Air Pollution and Health: a European Approach (APHEA)” studies in Europe. These have shown small but consistent effects of day-to-day variations in PM pollution and non-accidental and cardiovascular and respiratory mortality (7, 8).

2) A small number of studies have implicated long-term exposure to PM in reducing survival. The first of such studies was the Harvard Six Cities study which was published in 1993 (9). This study found that subjects living in communities with elevated fine particulate matter concentrations had a higher risk of dying over a 14-year follow-up period than subjects living in cleaner communities. A very large U.S. cohort study subsequently supported these findings (10) and further follow-up of these two cohorts has lent additional support (11, 12). Using data from these long-term studies, it has been estimated that effects of ambient PM exposure on life expectancy can be substantial, a reduction of one year or more (13).

3) Time series studies relate the day-to-day variation in air pollution to the day-to-day variation in numbers of deaths, hospital admissions, patients having symptoms etc. It has been argued that if air pollution advances death only by a few days or weeks in extremely frail individuals, the public health implications of the relationships seen in time series studies may be limited (14). Several investigators have now explored whether indeed this so-called ‘harvesting’ applies. If so, using longer averaging times in the time series would lead to reduction or even disappearance of the relationship between air pollution and mortality: subjects who were dying a few days or weeks early would not be around to die at their expected point in time. Thus, some days or weeks after high pollution days, fewer people would die than expected, canceling out the excess observed after the high pollution days. In contrast to this, using longer averaging times has produced higher rather than lower effect estimates (15). Still, the effect estimates from time series studies are less than those from long-term studies, suggesting that some of the long-term effects are not captured by variations of exposure in time over periods of weeks or months.

4) Another important issue concerns the existence of thresholds, concentrations of PM below, which no adverse effects on health occur. Several investigators have addressed this issue in the past decade. As an example, the exposure response function as found in the large NMMAPS study in the U.S. (16) was analyzed in various ways, none of which suggested a threshold for the effects of PM<sub>10</sub> on cardio respiratory mortality. The implication is that even at low levels of exposure, some effect on mortality is expected to occur. In the context of long-term studies, the issue of thresholds is more difficult to address, as there are no populations in which long-term exposure is absent. The ACS study discussed before suggests that also for long-term exposures, effects occur at very low levels of less than 10 µg/m<sup>3</sup> PM<sub>2.5</sub>.

5) For many years, research on health effects of PM was focused more on respiratory than on cardiovascular effects, despite the fact that in early episodes in London (1952) and the Meuse Valley (1930), many of the pollution deaths had been cardiovascular (6). In the last 15 years or so, however, much research has been devoted to cardiovascular effects, especially of PM, and this research has been both observational and experimental. As a result, there is now general consensus that PM does have serious cardiovascular effects, as evidenced from increased cardiovascular deaths after both long term and short term exposures, and from increased cardiovascular hospital admissions after high pollution days (17).

6) Various lines of *in vitro* and *in vivo* toxicological research have supported the biological plausibility of effects of PM on cardiovascular and respiratory health. Long-term animal experiments have been conducted in the U.S. and in Brazil, exposing sensitive animals to concentrated or ambient PM e.g., (18). This study found increased plaque formation after long term exposure to concentrated ambient PM<sub>2.5</sub> in sensitive mice fed normal and high fat diets. In combination with emerging human evidence of increased atherosclerosis in subjects exposed to elevated ambient

PM<sub>2.5</sub> (19), such studies suggest that long term PM exposure is associated with vascular defects which may develop into manifest cardiovascular disease and, ultimately, death.

### **Health Effects of Air Pollution in Asia**

Although most studies published so far are from developed countries, there is an increasing flow of publications coming from developing parts of the world where air pollution levels are often still higher than in developed countries. The remainder of this paper will focus on such studies, notably on studies conducted in Asia.

The primary source of information is the literature compilation made by the Health Effects Institute (HEI) as part of the HEI Public Health and Air Pollution in Asia program. In April 2004 a Special Report was published that reviewed 138 studies. An update from June 2006 added another 39 studies to this compilation. Studying health effects of high pollution exposures related to indoor biomass burning, and related to pollution from industry, energy production and traffic in large cities is understandably a matter of high priority, and it is these types of studies that are most abundant. Some studies have addressed pollution effects other than those related to indoor biomass smoke or outdoor urban exposures. These are studies of haze events related to forest fires, and studies of ‘dust’ events related to long-range transport of pollutant-enriched windblown desert dust.

### **Health effects of indoor exposure to biomass and coal smoke**

It has long been known that indoor exposure to biomass fuel combustion products may be very high in developing countries. Recent reviews include (20, 21). A study conducted some 20 years ago in Nepal (22) found increased respiratory infections in children in relation to indoor pollution caused by biomass burning. A recent report shows that this is still a persistent problem in Nepal (23) and likely elsewhere. Early reviews (24) drew attention to the fact that, at that time, more than half of the world population was probably exposed to high levels of indoor pollution from biomass burning, with severe consequences. The WHO Global Burden of Disease project recently estimated that in the developing world, 1,619,000 young children die every year from acute respiratory infections worsened by indoor biomass smoke exposure (25). A small case control study from India has also suggested that indoor biomass fuel use may be related to lung cancer (26). A review focused on acute respiratory infections in children documents the high burden of illness and death from this disease alone in relation to indoor biomass combustion product exposure in developing countries (27). Measurements using state of the art technology have confirmed that indoor PM levels can be extremely high in households using biomass for heating and cooking fuel. Levels of many hundreds of  $\mu\text{g}/\text{m}^3$  have been observed regularly, and such levels are much higher than outdoor PM levels even in highly polluted megacities (28).

Quite recently, it has been shown that rural women living in south China have higher indoor PM exposures than urban women, and have more chronic obstructive pulmonary disease (COPD) as a consequence (29).

Coal smoke exposure indoors may be particularly enriched with carcinogenic substances, and a case control study from China found that lung cancer was higher in households using coal for heating and cooking than in households using biomass fuels (30). A European multi center study also found increased risk of lung cancer with the use of solid fuels (coal as well as biomass) for cooking (31).

Exposure to pollutants generated from heating cooking oils to high temperatures has also been associated with lung cancer in non-smoking Chinese women (32). A meta-analysis of Chinese studies confirms that both indoor coal smoke and cooking oil vapors increase the risk of lung cancer (33).

### **Health effects of urban and industrial pollution in Asia**

We now come to studies which are more generally about health effects of urban and industrial air pollution on urban populations. As mentioned, the Health Effects Institute Public Health and Air Pollution in Asia program reviewed a large number of pertinent studies from Asia. Most of these were conducted in China, India, South Korea and Japan. Generally, studies from Asia have documented similar adverse health effects of air pollution as studies conducted in Europe and North America, despite large differences in pollution levels and demography. Some recent examples will be discussed below.

A panel study was conducted in the town of Kanpur, India (34). Air PM<sub>10</sub> levels ranged from about 100–500 µg/m<sup>3</sup> and were found to be associated with reduced Peak Flow on high pollution days. The same investigators compared respiratory health of adult inhabitants of two small towns in northern India with different pollution levels (PM<sub>10</sub> 113 vs. 76 µg/m<sup>3</sup>) (35). The more polluted town has much steel industry, the less polluted town only one seasonally operated sugar cane facility. Bronchitis, wheeze and shortness of breath were higher in men as well as women living in the more polluted town. Airway obstruction was twice more common in the more polluted town than in the less polluted town. Mistry and others (36) investigated children living in Challe, Sri Lanka, and Chandigarh, India. Challe was chosen as an example of a town where outdoor air is polluted by traffic and industrial emissions. In the same town, indoor air is polluted by kerosene stoves and firewood burning. Chandigarh is a new town without industrial emissions, and gas is used universally for heating and cooking. There was a more than two fold difference in reported wheeze (28.7 vs. 12.5%) between Galle and Chandigarh.

Several early time series studies covering the 1989–1990 period in Beijing documented increases in daily mortality and hospital admissions with increasing SO<sub>2</sub> and PM levels (measured as TSP) which ranged up to 400 µg/m<sup>3</sup> and 900 µg/m<sup>3</sup> respectively (37). A much more recent study from Shanghai, covering the March 2004–December 2005 period, found evidence of a relationship between daily fluctuations in PM<sub>2.5</sub> and all-cause, cardiovascular and respiratory mortality (38). PM<sub>2.5</sub> levels were 56 µg/m<sup>3</sup> on average, and ranged from 8–235 µg/m<sup>3</sup>. The authors also investigated the effect of coarse particles with a size range between 2.5 and 10 µm and could not demonstrate any effect (39). This observation is in line with a recent review on the topic of coarse PM effects (40). Kan and colleagues (38) compared exposure response relationships for PM<sub>10</sub> between Chinese and western studies, and found good agreement for acute effects on mortality. There was poor comparability for effect estimates of chronic effects, but in the absence of cohort studies from China, a direct comparison with results from North American cohort studies is not possible.

In China, a respiratory health study was conducted in the three cities of Lanzhou, Wuhan and Guangzhou with different air pollution levels. Respiratory health parameters of parents and children were measured, and significant and strong effects of air pollution, by district, were found on prevalence rates of cough, phlegm, persistent cough and phlegm, and wheeze for both the mothers and the fathers. In addition, the odds ratios increased as ambient total suspended particle concentration increased across the 3 urban districts (41). There was also a positive and significant association between total suspended particle levels and the adjusted odds ratios for cough, phlegm, hospitalization for diseases, and pneumonia in children. Furthermore, parental smoking status was associated with cough and phlegm, and use of coal in the home was associated only with cough prevalence (42). A study from Beijing found significant associations between SO<sub>4</sub><sup>2-</sup> concentration and total mortality and mortality due to cardiovascular disease, malignant tumour and lung cancer ( $r > 0.50$  in all cases) (43). The correlations were found not only between the current SO<sub>4</sub><sup>2-</sup> concentration and these mortalities, but also for SO<sub>4</sub><sup>2-</sup> levels measured up to 12 years prior to death, suggesting long-term effects of air pollution. No significant associations were observed for mortality from respiratory diseases and cerebrovascular diseases ( $r = 0.30–0.50$ ). This study indicates that the concentration of SO<sub>4</sub><sup>2-</sup> in air is a useful air pollution indicator in areas where coal is used as the main source of energy. Areas with high levels of SO<sub>4</sub><sup>2-</sup> experienced higher mortality owing to a variety of chronic diseases.

The Health Effects Institute report on Asian studies, published in 2004, includes a meta-analysis of published Asian time series studies. Effect estimates for all cause mortality in relation to PM<sub>10</sub> and SO<sub>2</sub> were remarkably similar to those found in multi center studies in North America and Europe. <http://pubs.healtheffects.org/view.php?id=3>

The HEI PAPA project has now produced its first published papers (44–47). In the cities of Hong Kong, Wuhan, Shanghai (all China) and Bangkok, Thailand, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub> and Ozone were all found to be associated with day-to-day variations in mortality, with effect estimates being equal to or larger than those reported from North America and Europe (47). In most analyses, there was little indication of a threshold concentration below which no effects on mortality were seen. Effects were larger in economically more deprived cities (Wuhan and Bangkok) which was attributed to populations being less able to protect themselves from high exposures. In Wuhan, there was also a clear interaction between pollution and temperature, pollution effects being higher on high temperature days (44). Within the Hong Kong population, effects were also shown to be larger for populations living in economically more deprived areas (46).

## Forest fire studies

A detailed analysis of forest fire smoke that covered a large area in south-east Asia in 1997 showed that in Malaysian cities, mortality was increased on high pollution days attributed to the forest fires (48). Effect estimates per  $\mu\text{g}/\text{m}^3$  PM were of the same order of magnitude as found in studies from Europe and North America, suggesting that the forest fire smoke had similar toxic characteristics as PM from combustion sources in the developed world.

Another study from Malaysia showed increased cardio respiratory hospital admissions in the city of Kuching in response to the forest fire smoke (49). A longitudinal study from Indonesia suggested that the forest fire smoke had an immediate deleterious effect on physical function and on coughing (50). An earlier report from Singapore showed that forest fire haze in 1994 had increased respiratory hospital admissions in children (51).

Studies from other parts of the world support the conclusion that wildfire smoke has deleterious health effects. One example is a study from Brisbane, Australia, showing increased hospital admissions on ‘bush fire’ days. This relationship was observed at relatively low PM10 concentrations that were on average only  $18 \mu\text{g}/\text{m}^3$  during bush fire days, with only two days above  $50 \mu\text{g}/\text{m}^3$  over a 3.5 year period (52). A study of wildfires occurring in 2003 in southern California found increases in respiratory symptoms, visits to a doctor, and school absenteeism among exposed children (53). PM10 levels reached values of up to  $250 \mu\text{g}/\text{m}^3$  for a five-day period in exposed communities.

Studies from southern Brazil show that in areas where air pollution is dominated by sugar cane burning, asthma hospital admissions are increased on cane burning days, frequently associated with PM10 levels in excess of  $100 \mu\text{g}/\text{m}^3$  (54).

A recent review on health effects of wood smoke concluded that wood smoke exposure is associated with multiple adverse health effects, and that there is no reason to assume that, on a per mass basis, such effects are less than those reported for other combustion particles (55).

### Asian dust storm event studies

Dust storm events, often originating in the Gobi desert in northern China and Mongolia, are a regular occurrence in Asia.

Chen and others (56) studied the effects of 39 such events in Taiwan, occurring between 1995 and 2000, comparing total and cause-specific mortality. PM10 levels were  $126 \mu\text{g}/\text{m}^3$  on ‘event’ days as opposed to  $58 \mu\text{g}/\text{m}^3$  on ‘non-event’ days, and there were non-significant increases in total and respiratory mortalities of 4.9% and 7.7% respectively. Significant effects on intracerebral hemorrhagic stroke were reported in a similar analysis (57). Emergency room visits for cardiovascular and chronic obstructive pulmonary diseases were found to be elevated on high dust event days compared to pre-dust periods in the period 1995–2002 (58). PM10 concentrations were  $123 \mu\text{g}/\text{m}^3$  during the high event days as opposed to  $46 \mu\text{g}/\text{m}^3$  in the pre-dust periods. A report from Seoul also noted a non-significant increase in mortality associated with 28 dust storm events that occurred between 1995 and 1998 (59). Whereas the dust storms originated in the north China Gobi desert region, the dust appears to be enriched with noxious pollutants when passing highly populated and industrialized areas in mainland China (60). Measurements conducted at a resort island in the north of China, remote from industrial or urban emissions have confirmed that airborne PM transported from the continent is indeed significantly enriched with combustion products from both coal and biomass burning (61).

### WHO Air Quality Guidelines: Global Update

The World Health Organization has recently established Global Air Quality Guidelines. The summary and full report are available at

[http://whqlibdoc.who.int/hq/2006/WHO\\_SDE\\_PHE\\_OEH\\_06.02\\_eng.pdf](http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf)

<http://www.euro.who.int/Document/E90038.pdf> The PM WHO guidelines are given below:

#### Guidelines

**PM2.5:**       **$10 \mu\text{g}/\text{m}^3$  annual mean**  
                   **$25 \mu\text{g}/\text{m}^3$  24-annual mean**

**PM10:**       **$20 \mu\text{g}/\text{m}^3$  annual mean**



**20µg/m<sup>3</sup> 24-annual mean**

These guideline values are low, reflecting the difficulty in identifying thresholds of effect for PM, both for short-term and long term effects. In recognition of the fact that such low levels are difficult to achieve in the short or even medium term, especially in developing countries, WHO has now developed for the first time a staged approach to air quality guidelines, suggesting intermediate targets, and showing with what health benefits achievement of such intermediate targets is likely to be associated. The interim targets for both the long term and the short-term guidelines are reproduced below:

**WHO air quality guidelines and interim targets for particulate matter: annual mean concentrations\***

	<b>PM<sub>10</sub></b> ( µg/ m <sup>3</sup> )	<b>PM<sub>2.5</sub></b> ( µg/ m <sup>3</sup> )	<b>Basis for the selected level</b>
Interim target-1 ( IT) -1	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level.
Interim target-2 ( IT) -2	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% [ 2-11% ] relative to the IT-1 level.
Interim target-3 ( IT) -3	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% [ 2-11% ] relative to the IT-2 level.
Air quality guideline( AQG )	<b>20</b>	<b>10</b>	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM.

\*The use of PM<sub>2.5</sub> guideline value is preferred.

**WHO air quality guidelines and interim targets for particulate matter: 24-hour concentrations\***

	<b>PM<sub>10</sub></b> ( $\mu\text{g}/\text{m}^3$ )	<b>PM<sub>2.5</sub></b> ( $\mu\text{g}/\text{m}^3$ )	<b>Basis for the selected level</b>
Interim target-1 (IT)-1	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over the AQG value).
Interim target-2 (IT)-2	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over the AQG value).
Interim target-3 (IT)-3 *	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase in short-term mortality over the AQG value).
Air quality guideline (AQG)	<b>50</b>	<b>25</b>	Based on relationship between 24-hour and annual PM levels.

\*99<sup>th</sup> percentile (3 days/year).

**Concluding Remarks**

Air pollution has negative effects on the health of populations worldwide. New studies from Asia suggest that short-term variations in PM and several gaseous pollutants are associated with short-term variations in mortality, with effect estimates being as high as or higher than those reported from North America or Europe. Studies on effects of long-term exposure to air pollution are still scarce in Asia, and conducting such studies is a priority and a challenge for the near future. A large fraction of the world population lives in China, India and other rapidly developing economies in Asia with associated large increases in energy production and consumption. Air pollution emissions are high, producing widespread “atmospheric brown clouds” with negative impacts on air quality at very large distances from the main source areas (62). It will be a major challenge to reduce the negative environmental effects of the economic development needed to provide better standards of living in this part of the world.

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